Background

The visual nature of biomedical knowledge

Human vision provides an extraordinarily powerful and effective means for acquiring information. Much of what we know about ourselves and our environment has been derived from images processed by various instruments, ranging from microscopes to telescopes which extend the range of human vision into realms beyond that which is naturally accessible.

In the life sciences, the relationships between biological form and function have been central to the understanding of health and disease throughout recorded history. Indeed, illustrations of anatomy are the most enduring and informative relics of a medieval medical science whose theory has long since been discarded. An intimate understanding of biological structure and its implications for therapy remains a *sine qua non* for medical specialties such as surgery, neurology, and radiology, as well as a learning challenge for all health professionals. Until recently, a fundamental limitation in the teaching and understanding of three dimensional structure was that media for reproducing images was two dimensional, as exemplified by the printed page and the plain film radiograph. The attempt to convey three dimensional content by presentation of two dimensional views forces upon the viewer an exercise in mental model construction which can be difficult and possibly fraught with inaccuracy; it endures as one of the major hurdles in the curricula of all health professions. For the trained viewer, who has long experience in the "intuitive" correlation and interpretation of 2-D sections with 3-D images, it is hard to determine how and under what circumstances such expertise was developed, so that it can be analyzed and transmitted in a more systematic manner to the practitioner and scientist in training.

Early three dimensional photographic technologies were brought to bear on the problem of human anatomy. The Bassett collection of anatomy images used the popular Viewmaster technology of matched stereo pairs of color transparencies to convey the essential qualities of depth and spatial orientation of gross anatomic structure. Still, the user of such photographic collections is limited to the static content of the images acquired at the time of image capture. No facility exists to move the object of study, to change the perspective of one's viewpoint at will in a manner analogous to having the physical object at hand, or to dynamically "enter" an object to disclose its internal representation.

New technologies

The emergence of the digital computer has provided a new technology for the acquisition, storage; manipulation, and display of complex images. Central to the capabilities of digital image display has been the development of large memory computers, specialized graphics processors, and high speed digital networks, along with robust and economical solid state scanning, high resolution display devices, and digital optical disks.

Pictures can be produced by computer in two fundamentally different ways[1]. The first is the representation of pictorial elements as geometrical objects, such as a collection of polygons whose shape and surface qualities can be calculated to produce a likeness of a real world object; the underlying representation is based on mathematical formulas for the geometrical primitives which combined make up the complete object.

The second method of picture representation by computer is sample based (also called pixel-based or image-based). In this method, the pictorial data may be thought of as individual points (pixels) in a large two dimensional field, which taken together portray an object recognizable by the viewer. In this scheme, the computer generally does not have an independent representation of objects within the image.

The distinction between the two picture representation methods is crucial to computer-based biomedical imaging. Most clinical images are acquired using sample-based methods. Thus, although the varying x-ray patterns produced by the computerized tomographic (CT) scanner can be rendered into a display which a physician interprets as various anatomical structures, to the computer the pixel components of the image are not manipulable as objects (e.g. internal organs) except to the extent that some tissues share a unique and homogenous radiodensity (e.g., bone). Yet for purposes of understanding the content of complex medical images, the identification of objects and object boundaries within sample-based images is essential.

Classification, i.e., the assignment of a sample or pixel to an organ, is a fundamental and difficult problem. The problem is typified by considering a CT sample that happens to fall at the boundary of bone and muscle tissue. The sample at that point represents some combination of both tissue types. Many classification techniques used today class such a pixel as one or the other tissue, thus introducing inaccuracies into the objects extracted from the sample set. Problems such as these may be overcome by better application of sampling methods, but the classification of objects within pixel sets remains a daunting problem.

NLM Long Range Plan

In 1985, the NLM commissioned a long-range planning effort involving over 100 experts in the fields of computer and library science, health professions education, and medical informatics research. Charged with looking five, ten and twenty years into the future, the planning panels identified major trends, impediments to progress, and "windows of opportunity" for the NLM to accommodate an information-rich future, or make elements of that future happen if appropriate to NLM's institutional mission.

Not surprisingly, the planning panels saw an increasing role for electronically-represented images in clinical medicine and biomedical research. As the world's foremost archive and distribution center for biomedical knowledge, the NLM was encouraged by the planning panel on Medical Education to explore the feasibility of building and making available electronic image libraries, much the same way that it maintains, indexes, and provides access to the biomedical literature[2].

However, the technologies to support such image libraries, associated high bandwidth communications, access and increasingly high resolution representation are new, and evolving rapidly in a number of disparate directions with heterogenous hardware and software requirements, and few if any standards for sharing of image data. To a public institution such as the Library, this flux translates into risk that prematurely launched programs will incur significant expense, yield image library data sets that are useable by only a small fraction of its constituency (or none at all), and be superseded by later developments which render its work obsolete and perhaps untransformable to new standards.

Current NLM digital imaging projects

Research and development involving digital images has been ongoing within the NLM's Lister Hill National Center for Biomedical Communications for several years. Appropriate to the Library's mission to serve as a national archive for biomedical information, investigations in the use of digital bit-mapped graphics to preserve page images of published material have been pursued in an Electronic Document Storage and Retrieval (EDSR) Program. The basic model for this research is the acquisition of high resolution (2,000 by 2,000 pixel) electronic images from biomedical texts, image enhancement and compression by computer algorithms, storage of page images on optical disk, and retrieval/display of page images linked to searches of NLM's bibliographic databases. The EDSR investigations have included extensive system software development and cost/throughput models to compare electronic archiving with more traditional modes of literature archiving such as microfilm.

An ambitious follow-on to the EDSR project is just beginning. Called the Machine Readable Archives in Biomedicine (MRAB), this project explores elements of document image "understanding", using automated algorithms to segregate text from graphics, and omnifont character recognition to convert printed text to machine readable character streams, while preserving nontextual regions in bitmapped form.

Color and monochrome digital representations of complex medical images such as microscopic tissue sections, 35mm dermatology slides, and clinical radiographs provide the focus for other Lister Hill Center projects. A key element of this research is the development of methods for automated assembly of overlapping digital image "tiles" into a composite high resolution image.

1988 3-D Anatomical Reconstruction Workshop

Innovative research on computer-based representation of three dimensional anatomic data is underway in a number of centers nationwide. In June of 1988 the National Library of Medicine convened representatives from eight academic medical centers involved with production and use of computer-based three dimensional anatomic imaging. The intent of this meeting was to review the current state of the art in 3-D imaging techniques, and to identify possible contributions that the Library might make to this field as a public agency.

Each of the university groups presented an overview of the types of activities at their own centers. In the aggregate, it became clear that the power, graphical display capabilities, and affordability of current computers are sufficient for many educational and research applications in 3-D anatomical imaging, and that there are unique merits to images rendered from digitized anatomic databases. The most dramatic of these is the ability to isolate, highlight, "reversibly dissect", rotate, and view from multiple angles single and grouped tissues, organs, body regions, and physiologic systems. Anecdotal evidence of the enthusiastic acceptance of 3-D imaging, especially for complex anatomic systems such as the central and peripheral nervous system, and the use of 3-D images in surgical planning, was presented.

The meeting participants pointed to the time and labor-intensive qualities of anatomic data acquisition as significant impediments to the wider use of 3-D anatomic reconstruction data in health professions education, treatment, research, and patient education. No spatial data set of anatomic coordinates for the complete human body exists in the public domain, and the project to develop such a data set would require more resources than any single academic group could reasonably devote to it.

Accordingly, it was the consensus recommendation of the group that the Library could contribute substantially to the advancement of the field by supporting the development of an image data set of an entire human male and female. This "Visible Human Project" would be carried out in two phases. The first would be acquisition of enhanced computed tomography images of representative, carefully selected and prepared male and female cadavers. The original cadaveric material would be preserved. The second component of the initial image acquisition would involve selective cryosectioning of the same cadavers used for development of the CT data set, and production of photographic images from appropriately-spaced sections. The next phase would be the contouring and digitization by anatomy experts, to define organs, tissues, and other structural entities in both CT and cryosectioned images. In terms of the two fundamental image representation methods discussed above, this phase would be the extraction of manipulable (geometric) objects from the pixel/sample based images obtained via radiography, magnetic resonance imaging, and photography.

The image library thus constructed would be made available by the Library in both electronic formats (such as CD-ROM discs) and as photographic image sets. A wide range of educational, diagnostic, treatment planning, and commercial uses was predicted by the group.

Charge to Image Planning Panel

To address the issues raised by the workshop on 3-D Anatomical Reconstruction, the current panel representing both the producers and potential users of computer-based biomedical images was convened. Members of the panel undertook presentations and discussion to answer the following questions:

1. What is the proper role for a public agency such as the NLM in relation to electronic imaging technologies? Should NLM change its current policy of exploring image library technologies to one of actually building and distributing image libraries?

2. Would such image libraries, if available today or in the near future, be used sufficiently by students, health sciences educators, and/or practitioners to justify the expense involved in their creation and maintenance?

3. Are new standards, data exchange conventions, or consortia arrangements needed to enhance the sharing of image data for purposes of education and health care?

4. Is the proposed 3-D visible human project a good start for undertaking the development of an electronic image library? If so, how should this project be pursued? Are there other equally or more compelling image projects the NLM should consider?